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Traditional knowledge and local adaptation strategies for climate resilient water management in Eastern Uganda

Daniel Omuna^a, Israel Olusegun Obaroh^a, Esther Ugo Alum^{a,b} , Afam Uzorka^c and Manal Awad Khiry^c

^aDepartment of Biological & Environmental Sciences, School of Natural & Applied Sciences, Kampala International University, Kampala, Uganda; ^bResearch Publications and Extension Department, Kampala International University, Kampala, Uganda;

^cDepartment of Physical Sciences, School of Natural & Applied Sciences, Kampala International University, Kampala, Uganda

ABSTRACT

Climate change exacerbates water insecurity across Eastern Uganda by increasing the frequency and intensity of droughts, floods, and unpredictable rainfall fluctuations, which substantially compromise water availability, accessibility, and quality. While Traditional Ecological Knowledge (TEK) and community-based adaptation strategies have been reported to support local resilience, their systematic incorporation into formal water management frameworks remains inadequate. A narrative review of peer-reviewed publications spanning 2015–2025 was conducted across Scopus, Web of Science, Google Scholar, and grey literature. The synthesis examined key thematic areas including climate stressors, Traditional Ecological Knowledge, household and community adaptation strategies, gender and intergenerational roles, and policy gaps. Communities employ TEK strategies including rainwater harvesting and communal governance structures wherein women, elders, and youth actively participate in water management decisions. While TEK approaches complement contemporary methods such as hybrid technologies, top-down project implementation frequently conflicts with established local practices. Significant policy gaps persist across several dimensions: stakeholder participation, gender inclusion, knowledge documentation, and resource allocation. Additionally, further research is warranted to assess the efficacy of adaptation strategies and to understand the dynamics of collaborative knowledge production. The integration of Traditional Ecological Knowledge into water policy frameworks, achieved through participatory and culturally grounded approaches that prioritize gender inclusion, can foster more equitable, sustainable, and climate-resilient water management systems.

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Traditional ecological knowledge; climate resilient water management; local adaptation strategies; Eastern Uganda; community based adaptation

Introduction

Mounting evidence indicates that climate change represents the primary driver of water insecurity in Eastern Uganda, particularly across districts including Butaleja, Bududa, and Mbale. This region exhibits considerable vulnerability to hydroclimatic extremes, with East Africa designated as a critical area for pronounced rainfall variability and persistent drought cycles, as documented by the Intergovernmental Panel on Climate Change (IPCC, 2022). In Eastern Uganda, these climatic shifts manifest through irregular seasonal rainfall patterns, severe flooding events, and extended dry periods that substantially compromise household water availability and agricultural output (Bueno Rubial & Lorenzo Arana, 2025; Ojara et al., 2020; Wanamama, 2024). Within this framework, climate-driven pressures constitute the primary source of water insecurity, generating cycles of vulnerability stemming from both excessive and insufficient water availability. Significant stressors include riverine flooding, prolonged droughts, intense precipitation events of short duration, and delayed or abbreviated rainfall seasons (IPCC, 2021; Omuna et al., 2024; UNFCCC, 2025).

To address these stresses, communities in Eastern Uganda have historically relied on TEK (Bamanya, 2017; Oyebola et al., 2021). This study adopts the definition of TEK provided by Berkes (2018) who defined it as the

CONTACT Esther Ugo Alum  esther.alum@kiu.ac.ug;  alumesther79@gmail.com; Daniel Omuna  daniel.omuna@kiu.ac.ug 
Department of Biological & Environmental Sciences, School of Natural & Applied Sciences, Kampala International University, Kampala, Uganda

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cumulative body of knowledge, practices, and beliefs developed through adaptive processes and transmitted across generations. While some literature uses ‘Indigenous knowledge’ interchangeably, we adopted TEK for the Eastern Ugandan context to ensure terminological precision. The term ‘Indigenous’ carries specific political and legal implications that do not align with the locally rooted, community-based knowledge systems of the region's diverse ethnic groups. TEK better reflects cultural appropriateness and avoids unintended associations with formal Indigenous status under international frameworks. The concept encompasses the cumulative body of knowledge, practices, and beliefs refined over generations, linking ecological stewardship with cultural identity (Berkes, 2018; Kembo & Utete, 2025). Rural households have historically managed irregular seasonal patterns through strategies including earthen pond construction, rainwater harvesting, and herbal water purification techniques (Kabo-Bah et al., 2021; Kimera, 2018). Recent calls for co-produced resilience frameworks and hybrid governance models reflect a growing global momentum to integrate traditional knowledge systems with Western science (Bremer & Meisch, 2017; Zvobgo et al., 2022). This study contributes to that effort by offering a context-specific analysis grounded in Eastern Uganda, translating global principles into locally relevant applications. As illustrated in [figure 1](#), TEK offers adaptive pathways that mitigate climate-induced water stress and reduce community vulnerability.

These local solutions are frequently overlooked within policy frameworks and undervalued by official water management programs, despite their demonstrated significance (Namara et al., 2024; Saber et al., 2025; Zvobgo et al., 2022). While boreholes and piped schemes represent common technological solutions favored in donor-supported interventions, they commonly fail when local expertise and community ownership are absent. Inadequate funding, insufficient maintenance, and functional degradation stemming from limited local engagement constitute the primary sources of technological failure. To preserve cultural heritage while providing contextually appropriate solutions to water scarcity, documenting and evaluating traditional practices and strengthening collaboration between communities and scientific institutions are essential (Martínez-Santos et al., 2020).

This narrative review examines the following thematic areas, focusing on how TEK mitigates climate stress impacts on local water security and adaptation outcomes in Eastern Uganda. i. Which climate stressors most directly compromise Eastern Uganda's water security, and how do their localized characteristics like duration, intensity, and timing shape vulnerability pathways? ii. How does the integration of TEK systems into the region's water resource management influence exposure, sensitivity, and adaptive capacity? iii. What local adaptation strategies operate at household and community scales to mitigate water insecurity, and how do resource access, roles, and responsibilities vary across gender, age, and other demographic dimensions? iv. How do policy frameworks, governance structures, and research agendas evolve when traditional approaches are incorporated into formal water governance and climate-resilient water management systems?

To move beyond a purely descriptive synthesis, this review uses the Climate–Water–Adaptation (CWA) Framework as an organizing analytical lens. The framework brings together the interaction of climate hazards, exposure and vulnerability, social–ecological systems thinking, and evidence concerning the role of traditional/local knowledge in African water-sector adaptation. Four analytical propositions (P1–P4) are used to structure comparison across the reviewed literature. These propositions are assessed through qualitative synthesis of recurring mechanisms, areas of convergence and divergence, and contextual conditions reported in the included sources. The review does not undertake primary statistical hypothesis testing or quantitative

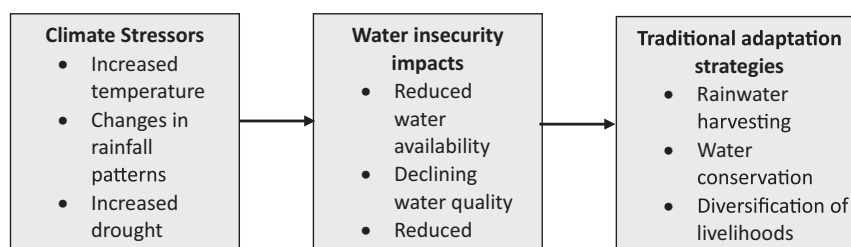


Figure 1. Conceptual linkages between climate stressors, water insecurity, and adaptation in Eastern Uganda. Source: Adapted from IPCC (2022); Zvobgo et al. (2022); and Omuna et al. (2024).

meta-analysis; consequently, numerical results reported by individual studies are treated as context-specific findings rather than pooled effect estimates or independent validation of the CWA framework.

Although this analysis focuses on Eastern Uganda, the findings may prove relevant to other semi-arid and flood-prone regions across sub-Saharan Africa facing similar hydroclimatic challenges (IPCC, 2022; Zvobgo et al., 2022). Figure 2 is a map of Eastern Uganda delineating the focal districts.

Although climate-related water insecurity in Uganda has been examined in previous studies, evidence concerning climate stressors, local ecological knowledge, gender and intergenerational roles, household and community adaptation, and formal governance is frequently treated in separate analytical domains (Bueno Rubial & Lorenzo Arana, 2025; Muyiira et al., 2025; Naiga et al., 2024; Namara et al., 2024; Ojara et al., 2020; Wanamama, 2024). This review addresses that fragmentation through the CWA framework. It makes three contributions. First, it organizes evidence on the relationships among hydroclimatic stressors, local knowledge, adaptation pathways, and water-security outcomes in Eastern Uganda. Second, it foregrounds gender and intergenerational dimensions of adaptation, including the roles of women, youth, elders, and community institutions. Third, it identifies policy entry points through which locally grounded knowledge and community institutions may complement scientific information, engineered water infrastructure, and formal governance. The review therefore treats TEK/local knowledge neither as inherently superior to scientific approaches nor as a substitute for formal water-management systems, but as a context-dependent source of knowledge and institutional capacity whose contribution requires critical evaluation.

Having established foundational concepts and underscored the significance of TEK in climate adaptation, the subsequent section examines existing literature on traditional knowledge systems and their application to water management in the context of changing climatic conditions.

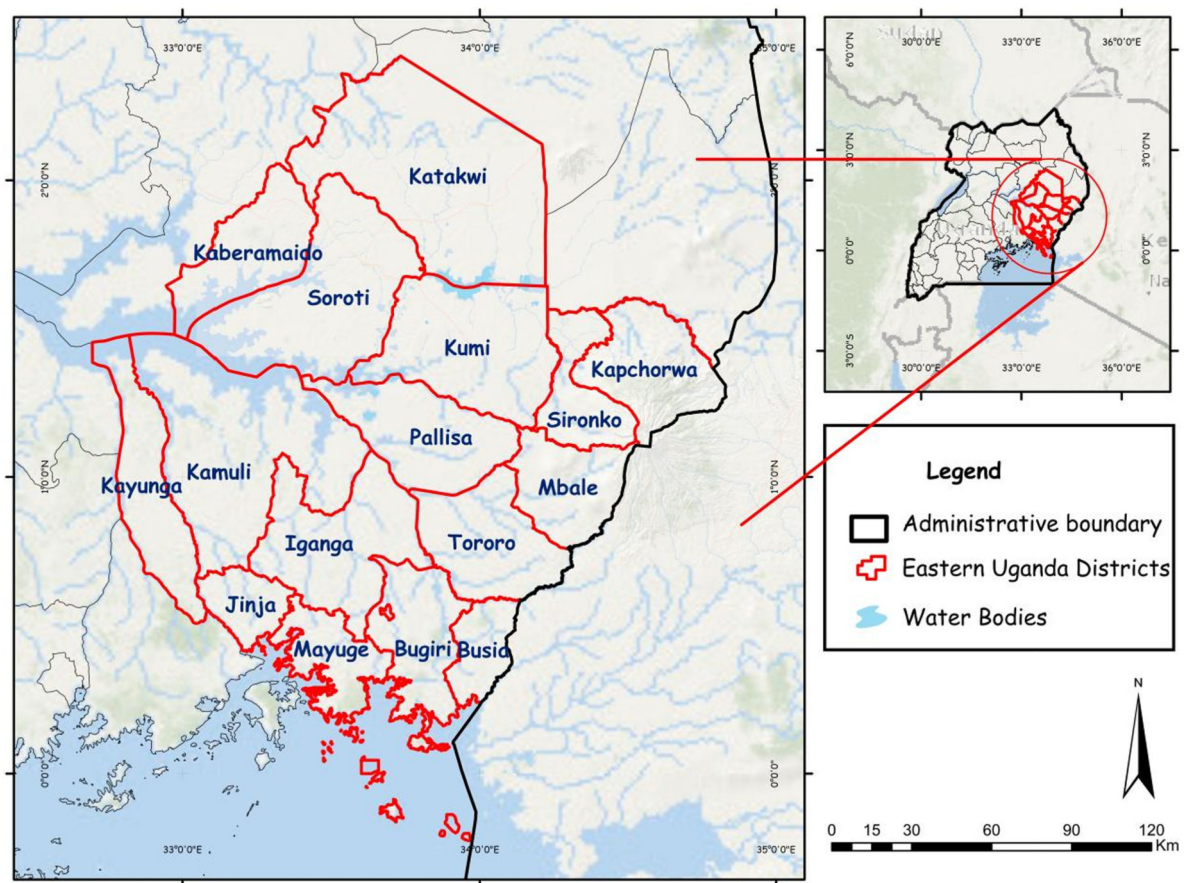


Figure 2. Map of Eastern Uganda delineating the focal districts. Source: Base map sourced from Uganda Bureau of Statistics (2023) and processed in QGIS for clarity and spatial accuracy.

Narrative review methodology

This study employed a narrative review methodology to synthesize evidence on TEK, climate-related water insecurity, and local adaptation strategies in Eastern Uganda. A narrative review approach was considered appropriate because the available literature encompasses heterogeneous forms of evidence, including peer-reviewed empirical studies, case studies, ethnographic accounts, policy documents, and community-based reports. The approach therefore enabled the integration of diverse forms of evidence while retaining attention to the social, ecological, institutional, and policy contexts within which water-management practices operate.

A structured and iterative literature search was undertaken using Scopus, Web of Science, and Google Scholar for publications covering the period 2015–2025. Search terms were progressively refined from broad concepts such as ‘traditional knowledge,’ ‘Traditional Ecological Knowledge,’ ‘climate adaptation,’ and ‘water management’ to geographically and thematically specific combinations incorporating terms such as ‘Eastern Uganda,’ ‘Mt Elgon,’ ‘Lake Kyoga,’ ‘water security,’ and ‘gender dimensions.’ Grey literature was additionally identified from relevant institutional sources, including the Ministry of Water and Environment, the Food and Agriculture Organization of the United Nations, and the United Nations Development Programme. Reference lists of relevant publications were also screened to identify additional studies and reports that addressed community-based water-management practices.

The initial search identified 237 records. Following assessment for thematic and geographical relevance, 76 sources published between 2015 and 2025 were retained for synthesis. The retained evidence base included 34 peer-reviewed articles, 18 government or policy documents, 16 NGO or community reports, and eight ethnographic accounts or case studies. Fourteen case studies and ethnographic accounts from the Mt Elgon sub-region and Lake Kyoga basin were used to provide more detailed contextual evidence concerning community experiences of water insecurity across different hydroclimatic settings. The review incorporated evidence derived from interviews, participatory rural appraisal, community studies, institutional reports, and other documented sources; however, no new interviews, surveys, experiments, or other primary data were collected for this study (Figure 3).

Data extraction was guided by a standardized analytical template covering climate stressors, TEK practices, household- and community-level adaptation strategies, gender and intergenerational roles, governance arrangements, and policy implications. The extracted evidence was organized through an iterative thematic coding process informed by established principles of thematic analysis (Braun & Clarke, 2006). Initial codes were developed from recurring concepts within the literature and subsequently grouped into five overarching thematic domains: (1) climate stressors, (2) Traditional Ecological Knowledge practices, (3) household and

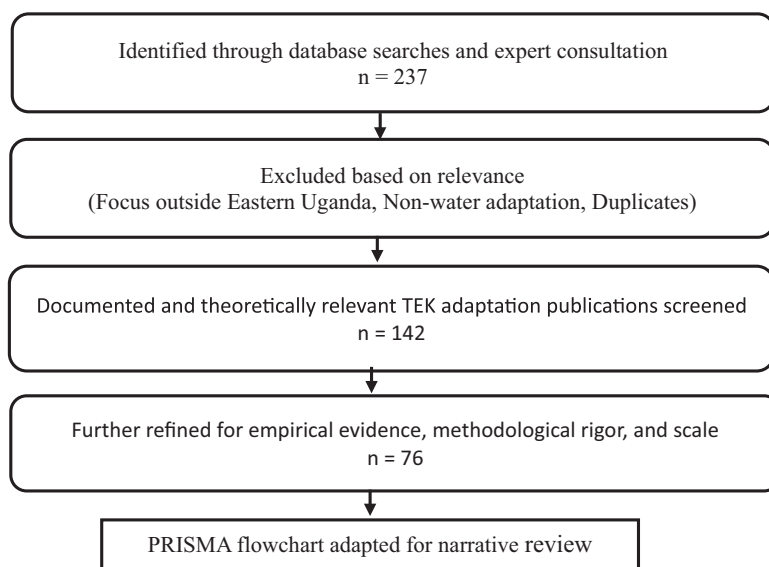


Figure 3. PRISMA-informed flowchart. Source: Adapted from standard PRISMA guidelines; Moher et al. (2009).

community adaptation strategies, (4) gender and governance roles, and (5) policy gaps and institutional responses.

To strengthen the credibility of the synthesis, evidence was triangulated across different source types. Findings identified in peer-reviewed studies were compared, where appropriate, with evidence from policy documents, institutional reports, and community-level studies. This triangulation was used to identify areas of convergence, divergence, and contextual variation rather than to treat agreement among sources as statistical validation. Particular attention was given to differences in geographical setting, study design, community characteristics, and institutional context because these factors influence the transferability of reported adaptation practices.

The thematic synthesis was subsequently aligned with the CWA Framework, which organizes the reviewed evidence around relationships among climate stressors, water-security challenges, TEK-related responses, adaptation pathways, governance conditions, and resilience outcomes. The framework was used as an analytical device to examine how the mechanisms identified in the literature interact across household, community, and institutional scales.

Importantly, the four CWA propositions (P1–P4) were assessed through qualitative synthesis of the reviewed evidence and were not subjected to primary statistical hypothesis testing or quantitative meta-analysis. Accordingly, the propositions function as analytical statements that guide interpretation and comparison across the reviewed literature. Evidence was examined for patterns that were consistent with, inconsistent with, or qualified the proposed relationships. Numerical findings reported in individual studies or institutional reports were treated as source-specific observations and not as pooled effect estimates generated by the present review. This distinction is important because methodological heterogeneity among the included sources precludes formal statistical aggregation and limits the extent to which quantitative findings can be generalized across Eastern Uganda.

The review therefore combines three complementary procedures: narrative synthesis to integrate heterogeneous evidence, thematic analysis to identify recurrent patterns within the literature, and framework-based interpretation to examine those patterns through the CWA analytical structure. This combination enables systematic consideration of climate stressors, local knowledge, adaptation pathways, gender and governance dynamics, and policy responses while remaining consistent with the interpretive nature of a narrative review.

The review has several methodological limitations. Because it does not employ a quantitative meta-analysis, it cannot estimate pooled intervention effects or establish statistical relationships among the variables incorporated in the CWA framework. Differences in study design, measurement approaches, geographic coverage, and reporting quality also constrain direct comparison among sources. In addition, some dimensions of TEK are transmitted orally and may be underrepresented in published academic literature. The findings should therefore be interpreted as a qualitative synthesis of available evidence and as a basis for identifying mechanisms, policy entry points, and priorities for future empirical research rather than as statistical verification of causal relationships.

This review employs three theoretical frameworks to advance beyond descriptive synthesis: (1) political ecology, which examines power dynamics and legitimacy within knowledge systems (Pelling, 2011); (2) Socio-Ecological Systems (SES) resilience, which evaluates adaptive capacity and feedback mechanisms (Folke, 2016); and (3) co-production of knowledge, which investigates mechanisms for incorporating TEK into formal governance structures (Bremer & Meisch, 2017). Together, these frameworks enable critical examination of integration possibilities, scalability constraints, and associated trade-offs.

To enhance transparency, we organized 76 retained sources by type, theme, and regional focus (Table 1). The evidence base encompasses peer-reviewed studies alongside various other documents, designed to reduce potential bias. The narrative approach carries certain constraints, however: the absence of quantitative meta-analysis limits statistical generalizability, and methodological heterogeneity may compromise comparability across sources. Our synthesis functions as an interpretive framework that identifies mechanisms and policy entry points, while recommending specific empirical evaluations such as comparative pilots and longitudinal studies to examine scalability and transferability.

Table 1. Summary of final 76 sources used in the review.

Source type	No. of sources	Principal themes covered	Regional focus
Peer-reviewed articles	34	• Climate stressors • TEK practices • Adaptation effectiveness	• Mt Elgon • Lake Kyoga • Floodplains
policy/government documents	18	• Water governance • Institutional gaps • Policy options	National and district level (MWE, NEMA)
NGO/community reports	16	• Local adaptation • Participatory projects • Implementation lessons	• Butaleja • Bududa • Mbale • Pallisa
Ethnographic accounts/case studies	8	• Cultural norms • Rituals • Intergenerational knowledge transmission	• Mt Elgon sub-region • Soroti • Kumi

Source: Compiled by the authors from the 76 retained sources (2015–2025), categorized by type, principal themes, and regional focus.

Theoretical foundations and analytical procedures of the climate-water-adaptation (CWA) framework

Rather than functioning as a static conceptual diagram, the Climate-Water-Adaptation (CWA) Framework (Figure 4) functions as an operational analytical tool designed to track resilience pathways from climate stressors to measurable outcomes. The framework rests on three well-established theoretical foundations: the IPCC (2022) risk triangle (hazard $\times$ exposure $\times$ vulnerability), Zvobgo et al. (2022) TEK adaptation ladder for African contexts, and Ostrom (2009) Social-Ecological Systems (SES) paradigm for multi-level governance. These foundations ensure theoretical coherence and facilitate systematic implementation. The framework operates through four consecutive analytical stages:

1. Stressor diagnosis: identifying hydroclimatic stresses, such as drought duration and flood intensity.
2. TEK Trigger: applying traditional knowledge such as women's flood memory and sacred site mapping as a reaction trigger.
3. Adaptation pathway selection: choosing among traditional, contemporary, and hybrid approaches.
4. Resilience evaluation: assessing outcomes against predetermined indicators, including water uptime percentage, cost per capita, equity score, and vulnerability reduction percentage.

Four analytical propositions guide application of the CWA framework. P1 considers whether stronger TEK-related knowledge inputs are associated with greater diversity in documented adaptation pathways; P2 examines evidence concerning the conditions under which hybrid approaches combine characteristics of traditional and contemporary systems; P3 examines the relationship between gender-inclusive participation

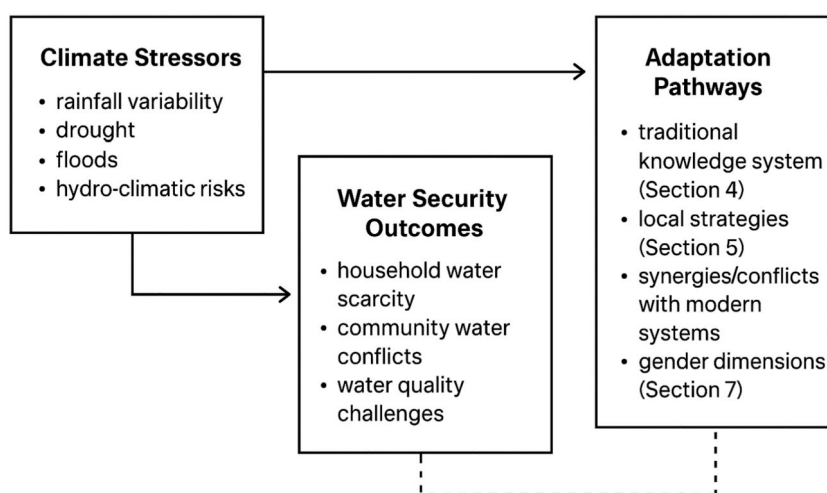


Figure 4. Climate–Water–Adaptation (CWA) Framework: Analytical pathway from stressors to resilience outcomes. Source: Developed for this study based on IPCC (2022); Zvobgo et al. (2022); and Ostrom (2009).

and equitable governance outcomes; and P4 considers how institutional and policy feedback influences scalability and continuity. These propositions are assessed qualitatively through the reviewed evidence and are not treated as statistically tested hypotheses.

The CWA Framework therefore provides a structured analytical approach for examining relationships among climate stressors, TEK, adaptation pathways, governance conditions, and resilience outcomes. Its purpose in this review is interpretive rather than predictive or statistically confirmatory.

Climate stressors threatening water security in Eastern Uganda

Rainfall patterns across Eastern Uganda have become increasingly erratic, characterized by delayed onset, shortened rainy seasons, and uncertain cessation (Ocen et al., 2021; Omay et al., 2023). According to Uganda's Ministry of Water and Environment, these hydroclimatic shifts create localized water insecurity in Eastern and Northeastern Uganda through disruptions to customary precipitation cycles and the emergence of unpredictable drought episodes (Atube et al., 2022). Data from the Famine Early Warning Systems Network (FEWS NET) (2023) document how late-season onset, mid-season dry spells, and irregular rainfall timing constrain crop development and diminish water availability. Extreme rainfall unpredictability and erratic precipitation events are increasingly widespread across Uganda, creating challenges for public infrastructure, water storage capacity, and agricultural production (Monitor, 2024). In select districts, historical rainfall records reveal declining average precipitation alongside increased intra-seasonal variability (Famine Early Warning Systems Network (FEWS NET), 2023). Table 2 summarizes rainfall variability and its implications for water security in selected districts of Eastern Uganda.

For rain-fed agricultural systems in Eastern Uganda, climate change presents a significant constraint, generating food insecurity for both human and livestock populations, income volatility, and seasonal water scarcity. The simultaneous occurrence of drought and flood hazards underscores rainfall variability; inter-annual precipitation fluctuations produce conditions of both shortage and surplus (Kishaija et al., 2024; Onyutha et al., 2024).

Inter-annual rainfall variability contributes to increased seasonal migration and crop loss, thereby heightening household vulnerability and diminishing adaptive capacity. However, cycles of vulnerability can be disrupted and community resilience strengthened through targeted social protection measures and small credit schemes implemented following shocks. In low-lying areas such as Butaleja and Budaka, flooding exacerbates household financial strain and labor constraints for community maintenance by causing rapid infrastructure deterioration, increased health expenditures, and population displacement (Mudondo et al., 2019; Sliuzas et al., 2023). Heavy rainfall-induced flash floods contaminate surface water sources, compromise shallow well systems, and elevate the risk of waterborne disease transmission (Erima et al., 2022; Monitor, 2023). Recurrent landslides triggered by soil saturation in Bududa disrupt spring and stream hydrological systems while displacing settlements (Khanakwa, 2023; Namuenge et al., 2024).

In rural Eastern Uganda, groundwater remains the primary source of drinking water, accessed primarily through shallow wells, boreholes, and protected springs. However, drought conditions lower the water table, causing shallow wells to experience seasonal depletion (Bunyanga, 2023; Ogwal, 2024). Additionally, pollution, overuse, and agricultural encroachment increasingly threaten surface water resources, including wetlands and streams. The principal groundwater and surface water challenges in the region are detailed in Table 3 (Byakatonda et al., 2021; Mukasa et al., 2020). As climatic variability converges with growing human consumption, water insecurity emerges as a multifaceted challenge affecting supply, quality, and accessibility alike.

Eastern Uganda's biological diversity spans three distinct physiographic zones: semi-arid margins (Kaliro, Namutumba), lowland floodplains (Butaleja, Budaka), and steep highlands (Mt. Elgon districts). Each

Table 2. Rainfall variability and its implications for water security in selected districts of Eastern Uganda.

District	Average annual rainfall (mm)	Notable variability (2000–2020)	Water security implications
Mbale	1,200–1,500	Late onset; reduced March–May rains	Crop failures; drying of shallow wells
Bududa	1,800–2,000	Short intense rainfall; longer dry spells	Floods in lowlands; scarcity in uplands
Butaleja	1,300–1,600	Seasonal shifts; unpredictable dry spells	Food insecurity; reliance on wetlands

Source: Compiled from Atube et al. (2022), FEWS NET (2023), Ocen et al. (2021), and Monitor (2024).

Table 3. Climate related stressors and socioeconomic implications for groundwater and surface water sources.

Water Source Type	Climate-Related Stressor	Socio-economic Implications
Shallow wells	Drying during drought; contamination during floods	Seasonal shortages; waterborne diseases
Boreholes	Uneven distribution: some fail in prolonged droughts	Long walking distances; reliance on unsafe sources
Streams & rivers	Flooding, sedimentation, pollution from run-off	Contamination; increased water treatment needs
Wetlands	Drying in drought; encroachment for farming	Loss of buffer capacity; scarcity during dry spells

Sources: (Byakatonda et al., 2021; Mukasa et al., 2020).

subregion faces specific hydroclimatic vulnerabilities. Highland areas are particularly susceptible to soil erosion, landslides, and spring deterioration (Sennoga et al., 2022). In the lowlands, wetland degradation and recurrent flooding present significant environmental challenges (Walekhwa et al., 2022). Semi-arid regions experience distinct pressures, including prolonged drought conditions and the depletion of shallow groundwater resources (Nansamba et al., 2022).

Inter-annual rainfall variability in Eastern Uganda generates vulnerability cycles intricately linked to socioeconomic conditions. Delayed rainfall onset reduces crop productivity and household earnings, triggering labor migration and asset liquidation that compromise future adaptive capacity. Flooding intensifies these challenges by damaging critical infrastructure and raising healthcare expenditures, thereby redirecting resources away from climate adaptation initiatives (Palmer et al., 2023). Structural constraints including poverty, insecure land rights, and inadequate access to credit inhibit both infrastructure repair and the uptake of improved agricultural technologies, amplifying the frequency of climatic impacts (Pierri et al., 2025). These interconnected processes disrupt local labor supply and collective stewardship of TEK systems, establishing reinforcing cycles that perpetuate poverty and out-migration while constraining recovery capacity. Explicitly linking climate variability to these socioeconomic pathways enriches the analytical framework by demonstrating how stressor frequency shapes vulnerability profiles and determines the efficacy of TEK-based interventions.

Traditional ecological knowledge systems and water resource management

This section investigates the cultural and ecological foundations of TEK within Eastern Uganda's context, extending the climate stressors analyzed previously. TEK fundamentally influences water utilization, conservation, and distribution practices in Eastern Uganda by integrating empirical ecological observation with deeply held cultural values (Sharifian et al., 2022; Sheppard et al., 2024). Unlike contemporary approaches centered on built infrastructure, TEK connects water management with traditional governance structures, ritual practices, and collective responsibility. The framework emphasizes the interdependence of ecological adaptation, cultural values, and local knowledge in managing water resources, as shown in Figure 5. Moreover, TEK remains adaptive, continuously adjusting to evolving social and environmental conditions, as illustrated in Figure 5.

Eastern Ugandan communities have long employed economical and ecologically sound water harvesting and conservation techniques that predate contemporary technological solutions. Among these established practices are ebidiba (earthen ponds), banana-leaf gutters, contour bund terracing, and wetland conservation

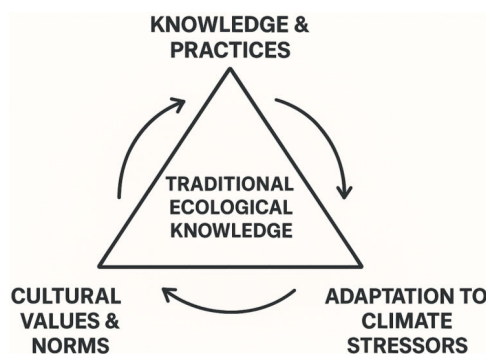


Figure 5. Conceptual framework of Traditional Ecological Knowledge in water resource management. Source: Developed for this study; informed by Berkes (2018); Sharifian et al. (2022); and Sheppard et al. (2024).

(Table 4). Such traditional methods remain integral to community-based water management, supporting water accessibility during drought periods, enabling household rainwater capture, reducing surface runoff, promoting groundwater recharge, and alleviating seasonal water scarcity (Bays, 2022; Turyahabwe et al., 2022).

TEK provides cost-effective, locally tailored approaches to water management, though its success is contingent on the type and intensity of climate-related challenges. Earthen ponds (ebidiba), for instance, can retain water for 3–5 months during seasonal droughts at less than 10% of the expense required for borehole construction (Kabo-Bah et al., 2021). Yet these structures remain susceptible to failure when exposed to flash floods or extended droughts exceeding six months (Bunyanga, 2023). Broader implementation is constrained by land tenure systems, labor constraints, and demographic pressures; household-based interventions often prove impractical in peri-urban contexts (Wanamama, 2024). From a Socio-Ecological Systems (SES) perspective, TEK strengthens social memory and response diversity. Conversely, restrictive sacred spring taboos can hinder societal adaptation by controlling resource access. This presents a fundamental tension between the cultural legitimacy of TEK and the technological dependability of modern infrastructure. Hybrid systems that integrate TEK's strengths with contemporary technical reliability such as solar-powered pumps managed by community water committees (Kimbowa et al., 2024) offer a promising pathway forward.

Furthermore, local communities developed and maintained strategies to ensure access to clean drinking water. Storage techniques emphasized durability, cleanliness, and thermal regulation, while purification often relied on natural materials and processes. Key traditional methods of purification and storage are illustrated in Figure 6.

As illustrated in Figure 6, several low-cost, environmentally sustainable techniques remain viable for contemporary climate adaptation, including the use of Moringa seeds for turbidity reduction and storage of water in clay vessels to maintain coolness and freshness.

Conventional water management systems fostered collective stewardship by embedding cultural and spiritual principles into practice. Rituals preceded access to communal wells, reflecting the reverence accorded to water as a shared asset, while sacred springs and rivers were protected from pollution and overexploitation through cultural taboos (Muyiira et al., 2025; Obiero et al., 2023). By weaving ecological conservation into communal life, these cultural frameworks enabled the sustainable management of water resources across generations, as demonstrated in Table 5.

Table 4 . Traditional water harvesting and conservation practices in Eastern Uganda.

Practice	Description	Function in water management
Ebidiba (earthen ponds)	Hand-dug pits lined with clay soil to store rainwater	Household and livestock water during dry spells
Banana-leaf gutters	Use of banana leaves to channel roof runoff into pots	Rainwater harvesting at household level
Terracing and contour bunds	Soil conservation structures on hillsides	Reduced runoff, improved groundwater recharge
Wetland preservation	Protection of wetlands as communal water sources	Buffering against seasonal scarcity

Source: Developed for this study based on Bays (2022), Kabo-Bah et al. (2021), Turyahabwe et al. (2022), and community practices in Eastern Uganda (Bunyanga, 2023; Wanamama, 2024).

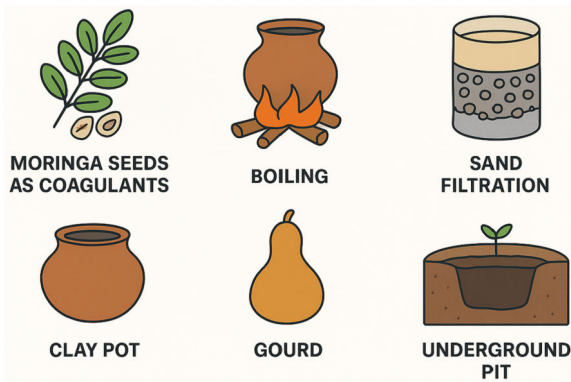


Figure 6. Traditional water purification and storage techniques used in Eastern Uganda. Source: Based on Kabo-Bah et al. (2021); Raphasha et al. (2025); and community practices documented in Muyiira et al. (2025).

Table 5. Cultural norms and beliefs shaping traditional water management.

Cultural value/belief	Associated practice	Impact on water management
Sacred springs and rivers	Prohibitions on bathing, washing clothes, or polluting	Ensured purity and conservation of sources
Rituals before well use	Seasonal opening ceremonies led by elders	Reinforced community ownership and stewardship
Taboos on trees cutting near water points	Preservation of vegetation around springs and wetlands	Maintained recharge areas and reduced siltation
Communal labor norms (bulungi bwansi)	Collective cleaning and maintenance of wells	Ensured sustainable use and equitable access

Source: Synthesized from Muiyira et al. (2025), Obiero et al. (2023), and ethnographic accounts in the Mt. Elgon sub-region (Namuenge et al., 2024).

Research indicates that TEK in Eastern Uganda encompasses both cultural institutions including ceremonial practices and communal governance structures and practical techniques such as water collection and treatment methods. Although TEK is not considered inherently superior to other approaches, it demonstrates considerable utility in specific social and environmental contexts, especially when integrated with targeted technical support and participatory governance frameworks. Oral histories from the Mount Elgon region illustrate this applicability: earthen ponds (ebidiba) historically provided three to five months of water storage at minimal cost, allowing households to endure prolonged drought periods (Walekhwa et al., 2022). Similarly, banana leaf gutters and terraced systems which function comparably to modern watershed management but at reduced expense efficiently redirect rainfall and minimize runoff, thereby enhancing soil conservation and water retention.

Evidence from the reviewed literature indicates that rainwater harvesting, small water-storage structures, and community-managed water systems can supplement water availability during seasonal scarcity. However, reported outcomes vary across locations and intervention types, and the available evidence does not support a pooled quantitative estimate for Eastern Uganda. Their effectiveness depends on factors including maintenance, local participation, technical design, land access, and institutional support.

Local adaptation strategies for climate resilient water management

This section examines the localized dimensions of TEK by exploring its practical applications within household and community contexts. In Eastern Uganda, households implement cost-effective, community-driven techniques including rainwater harvesting, earthen storage ponds, banana-leaf gutters, and clay-pot filtration to address climate-related water scarcity (Aggrey et al., 2024; Mutai & Chege, 2023). While these practices serve as foundational elements of local resilience, their sustained effectiveness and scalability depend on institutional support. The most common household-level adaptation strategies documented across the region are presented in Table 6 (Ministry of Water & Environment (MWE), 2022). Integrated into daily routines, these approaches provide adaptive capacity where formal water infrastructure is either absent or unreliable. This discussion emphasizes the practical implementation, adaptation, and long-term sustainability of TEK at the local level in response to climatic pressures.

Empirical evaluations provide conditional support for hybrid water innovations. According to FAO (2021), community-constructed sand dams in selected areas of Mbale and Bududa increased dry-season water availability, contingent on consistent desilting and sustained community participation. Similarly, FAO reports that household rainwater harvesting tanks using rooftop collection can reduce reliance on unsafe water sources during drought periods. While these findings demonstrate measurable advantages for hybrid

Table 6. Household level adaptation strategies for water security in Eastern Uganda.

Strategy	Description	Climate resilience contribution
Rainwater harvesting	Rooftop collection using iron sheets, plastic drums	Provides water during dry spells; reduces reliance on unsafe sources
Shallow well maintenance	Families reinforce well walls with stones or bricks	Prevents collapse during floods; prolongs usability
Seasonal water rationing	Households regulate usage during prolonged droughts	Ensures limited water lasts longer; promotes conservation
Clay pot storage	Use of clay pots/gourds to store water	Preserves water quality and reduces evaporation losses
Sand dams built by youth groups	Small earthen dams along seasonal streams	Stored water for dry seasons; reduced runoff erosion
Integrated crop–water systems	Linking water harvesting ponds with crop irrigation	Improves food security; diversified water use

Source: Authors' synthesis from reviewed literature (Aggrey et al., 2024; Naiga et al., 2024; Namara et al., 2024).

approaches, challenges related to maintenance, land tenure, and financial sustainability remain significant considerations.

Community-driven initiatives, typically coordinated by local leaders or water user committees, represent a collective approach to addressing water insecurity (Kimbowa et al., 2024). These strategies ensure equitable access to shared water resources while complementing household-level interventions. During periods of water scarcity, households follow structured schedules for accessing boreholes and wells to minimize conflict. Local committees manage user fees, oversee maintenance operations, and coordinate communal cleaning of wells and springs. Elders and traditional leaders further contribute by mediating disputes, enforcing cultural norms against water contamination, and mobilizing community labor (Kimbowa et al., 2024). Collectively, these practices mitigate the risk of overexploiting vulnerable water sources while reinforcing social cohesion.

Community-driven efforts, often organized by local leaders and water user committees, represent a collective approach to addressing water insecurity (Kimbowa et al., 2024). These initiatives ensure equitable access to shared water resources while complementing household-level strategies. During periods of water scarcity, households follow coordinated schedules for boreholes and well access to minimize conflict. Local committees manage user fees, oversee maintenance operations, and coordinate communal cleaning of wells and springs. Elders and traditional leaders play an additional role by mediating disputes, enforcing norms against water contamination, and mobilizing community labor (Kimbowa et al., 2024). Collectively, these practices reduce the risk of overexploiting fragile water sources while strengthening social cohesion.

Household and community-based approaches present distinct advantages and limitations when situated alongside contemporary interventions, particularly regarding their long-term viability and capacity for expansion. TEK techniques typically operate at modest scales and are tailored to specific local ecological and social conditions, which affords them considerable flexibility and cost-effectiveness. Community-constructed sand dams in Mbale and Bududa exemplify this approach: they enhance dry-season water availability while requiring substantially lower investment than donor-funded piped infrastructure and fostering local stewardship. Although clay pot filters and banana leaf gutters necessitate seasonal upkeep, earthen ponds and sand dams yield benefits extending across multiple years. Contemporary technologies such as solar-powered shallow well pumps deliver significant labor reductions but remain contingent upon institutional capacity and the accessibility of replacement components. Effective scaling in peri-urban settings demands a synthesis of traditional practices with technical resources including engineering expertise and formalized maintenance protocols to sustain improvements while maintaining community agency (Castelli et al., 2022).

Synergies and conflicts with modern water management approaches

This section examines hybrid approaches that integrate TEK with contemporary technologies. It presents practical applications, including collaborative development of borehole maintenance protocols informed by local stewardship practices, integration of household-based rainwater harvesting techniques into formal designs, and community-driven monitoring systems coordinated with district-level maintenance operations. Additionally, it considers hybrid financing frameworks that combine local investment with external donor support. Table 7 demonstrates the institutional synergies and arrangements that facilitate these approaches, emphasizing how alignment between TEK and technical innovation produces more resilient, contextually appropriate outcomes.

This section examines hybrid techniques that combine contemporary technologies with TEK. It presents practical solutions, including the incorporation of household practices into rainwater harvesting systems, collaborative development of borehole maintenance protocols with local stewardship regulations, and

Table 7. Synergies between traditional and modern water management practices.

Traditional practice	Modern complement	Synergy outcome
Rainwater harvesting with banana leaves or pots	Rooftop harvesting with iron sheets and plastic tanks	Expanded storage capacity; improved hygiene
Community well maintenance (stone lining)	Borehole maintenance by trained committees	Reduced downtime of water sources; community ownership
Cultural taboos against polluting springs	Chlorination and water treatment programs	Reinforced water quality control
Communal labor (bulungi bwansi) for cleaning wells	NGO-supported infrastructure rehabilitation	Lower repair costs; stronger local participation

Source: Authors' synthesis from reviewed literature (Aggrey et al., 2024; Naiga et al., 2024; Namara et al., 2024).

community-based monitoring aligned with district maintenance schedules. Additionally, the section explores hybrid financing models that leverage donor funding alongside local contributions. [Figure 7](#) illustrates the institutional arrangements and synergies underlying these approaches, demonstrating how TEK and technological innovations together generate outcomes that are both more sustainable and better suited to local contexts.

Conflicts frequently emerge when contemporary initiatives disregard established systems, despite potential synergies. Governance structures, resource allocation, and social equity represent common friction points (Ahabwe et al., 2022; International Institute for Sustainable Development (IISD), 2018). [Table 8](#) identifies the principal sources of such tensions (Ministry of Water & Environment (MWE), 2022). Infrastructure projects risk failure when modern approaches override cultural practices, particularly through inadequate stakeholder ownership or inequitable benefit distribution, as illustrated in [Table 8](#). Hybrid governance frameworks can address critical tensions, including those between local autonomy and state authority, cultural legitimacy and technical reliability, and immediate coping mechanisms versus long-term sustainability. Community-operated boreholes exemplify this approach: they reduce women's water-fetching time by two to three hours (NEMA, 2025), provided that TEK norms inform governance structures; without such integration, elite capture can undermine equitable outcomes (Ahabwe et al., 2022).

The data presented in [Tables 7 and 8](#) and [Figure 4](#) reveal both conflicts and synergies within the dynamic relationship between traditional and modern water management approaches. Synergies emerge when contemporary systems incorporate conventional methods, yielding hybrid solutions that demonstrate effectiveness and social acceptability. Conversely, conflicts arise when external approaches neglect community participation and cultural legitimacy. Developing integrated water management methods that are simultaneously culturally grounded and climate resilient hinges on understanding these relationships. [Table 9](#) provides a comparative synthesis that evaluates traditional practices, modern approaches, and hybrid systems according to key performance criteria.

This synthesis reveals that TEK, while advantageous in cultural legitimacy and cost-effectiveness, faces significant scalability constraints. Conversely, modern water systems provide extensive coverage but may encounter sustainability and community ownership challenges if they lack cultural integration. Hybrid approaches such as solar-powered shallow wells managed by traditional committees or contemporary

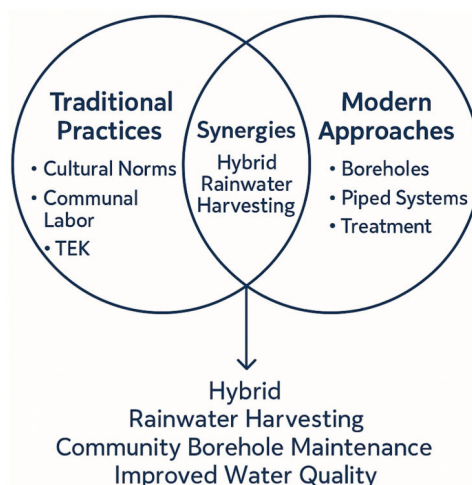


Figure 7. Overlap of traditional and modern water management systems: Synergies and hybrid outcomes. Source: Developed for this study based on Kabo-Bah et al. (2021), Muyiira et al. (2025), Raphasha et al. (2025).

Table 8. Conflicts between traditional and modern water management approaches.

Conflict area	Description	Implication for water security
Top-down project design	Donor-driven schemes often exclude community input	Infrastructure abandonment; low adoption
Cultural disregard	Ignoring taboos or rituals around water sources	Loss of trust; reduced community stewardship
Unequal access	Piped systems serving trading centers but not remote villages	Widened rural–urban water inequality
Gender exclusion	Women's roles in traditional knowledge not recognized	Missed opportunities for inclusive adaptation

Source: A synthesis of the reviewed literature, as compiled by the authors (Aggrey et al., 2024; Naiga et al., 2024; Namara et al., 2024).

Table 9. Comparative characteristics, potential contributions, and limitations of traditional, modern, and hybrid water-management approaches in Eastern Uganda.

Criteria	Traditional practices (TEK)	Modern approaches	Hybrid systems (TEK + modern)
Sustainability	Long-standing, ecologically embedded, minimal resource depletion.	High efficiency but dependent on external inputs & funding.	Combines ecological stewardship with technical durability.
Cost-effectiveness	Low financial costs; high reliance on community labor.	High capital and maintenance costs; risk of donor-dependency.	Reduced costs via local ownership; donor support supplements.
Scalability	Effective at household/community scale; limited for urban growth.	Scalable to regional/national level but socially fragile.	More scalable when community norms guide infrastructure use.
Community Ownership	High practices reinforced by culture, rituals, and taboos.	Often low projects collapse without local engagement.	Stronger adoption: modern tech is supported by traditional norms.
Gender Inclusivity	Women central at household level; elders/youth play key roles.	Often male dominated governance, limited inclusivity.	Women's knowledge + youth innovation improve outcomes.
Effectiveness	Reduces scarcity seasonally (ponds provide 3–5 months).	Ensures large-scale supply but vulnerable to breakdown.	Greater resilience: e.g. solar pumps with community committees.
Health Outcomes	Traditional purification improves safety but inconsistent.	Chlorination and treatment are more reliable but costly.	Combined methods provide safe and affordable water access.

Source: Authors' synthesis from reviewed literature (Aggrey et al., 2024; Naiga et al., 2024; Namara et al., 2024).

rainwater harvesting combined with local techniques offer a more balanced solution. These examples illustrate how integrating TEK with modern technology enhances resilience by creating adaptive solutions that are simultaneously practical and socially acceptable to communities.

Comparative analysis using the CWA framework

Across the reviewed evidence, the CWA framework is best interpreted as a heuristic for organizing relationships among climate stressors, locally grounded knowledge, adaptation choices and governance conditions. Research in the Mt Elgon Water Tower demonstrates that local observations can provide context-specific information on changes in water availability and support participatory environmental planning (Kimbowa et al., 2024). Research on community-managed water systems in Uganda further indicates that operation and maintenance outcomes depend strongly on institutional arrangements and collective action (Naiga et al., 2017; Naiga, 2018). Gender-focused evidence shows that women play important roles in water management while continuing to face substantial constraints in formal decision-making (Naiga et al., 2024). At the continental scale, Zvobgo et al. (2022) found evidence that indigenous and local knowledge influences a range of water-sector adaptation responses, while emphasizing that evidence of effectiveness and scalability remains incomplete. Collectively, these studies provide qualitative support for examining participatory and hybrid adaptation pathways, but they do not establish a pooled effect size or universal superiority of one pathway.

Gender dimensions in traditional water adaptation

In Eastern Uganda, gender significantly shapes traditional water adaptation practices. Cultural expectations and adaptation demands establish distinct roles for women, men, and young people in water access, management, and knowledge transmission (McKinney & Wright, 2021; Naiga et al., 2024; National Environment Management Authority (NEMA), 2020). Men typically occupy leadership positions within communal governance structures, while women are frequently recognized as custodians of water knowledge at the household level (Galabuzi et al., 2021; Kimbowa et al., 2025; McKinney & Wright, 2021). Community adaptation strategies are shaped by multiple factors, particularly the responsibilities of women, who bear primary responsibility for collecting and managing domestic water. Their detailed knowledge of seasonal water availability, purification methods, and water conservation practices proves essential for household-level adaptation. Table 10 presents the common gendered roles evident in traditional water adaptation systems (Food & Agriculture Organization (FAO), 2021). As illustrated in Table 10, gender responsibilities operate in a complementary manner: men support infrastructure development, women sustain household resilience, and elders transmit cultural knowledge.

Gendered access to water is also shaped by cultural customs. Women face considerable hardships, including physical strain and security risks, stemming from their typical responsibility to spend many hours daily collecting water (Asaba, 2015; Colding-Jørgensen et al., 2023). Conversely, men are more heavily represented

Table 10. Gendered roles in traditional water adaptation in Eastern Uganda.

Gender group	Roles in water adaptation	Contribution to climate resilience
Women	Collect water, store it in clay pots, apply purification by boiling or filtration, and manage rationing	Safeguard household water quality and availability
Men	Construct and maintain wells, manage irrigation channels, mobilize communal labor	Provide technical and infrastructural support
Youth	Assist in carrying water, digging shallow wells, participating in communal clean-ups	Provide labor and innovation in adaptation
Elders	Mediate water-related conflicts, enforce taboos, transmit ecological knowledge	Strengthening governance and cultural continuity

Source: A synthesis of the reviewed literature, compiled by the authors (Aggrey et al., 2024; Naiga et al., 2024; Namara et al., 2024).

in community-level water allocation decision-making processes (Asaba, 2015; Luigi et al., 2021). While conventional institutional structures often reinforce gendered divisions of labor, they can simultaneously create pathways for empowerment when diversity is prioritized. Women's involvement in local water committees, for example, has demonstrably improved accountability and borehole maintenance (Mandu & Karyeija, 2024). Youth-led technological innovations such as solar-powered pumps have likewise reduced the burden of long-distance water collection for women (National Environment Management Authority (NEMA), 2025). Policy frameworks that recognize and integrate women's ecological knowledge can further strengthen the collaborative development of adaptation solutions (National Environment Management Authority (NEMA), 2025).

In traditional water management, gender functions not merely as a social category but as a determinant of adaptive capacity. A multifaceted adaptive framework emerges through the convergence of women's stewardship of water knowledge, men's engagement with infrastructure development, youth labor contributions, and elders' cultural authority. When leveraged inclusively, these differentiated roles substantiate climate-resilient water governance. However, systemic vulnerabilities can persist should women's and young people's contributions remain undervalued or unacknowledged. Addressing these disparities through inclusive adaptation strategies is essential to preserving both the resilience and equity of traditional knowledge systems (Anjum & Aziz, 2025).

Comparative analysis demonstrates that traditional systems' gendered roles present both strengths and limitations when evaluated against contemporary approaches. Women's established expertise in rationing, storage, and water purification represents a cost-effective asset, yet formal water governance frameworks often undervalue these contributions, constraining opportunities to expand and institutionalize such practices. More recent research by Naiga et al. (2024) found that women's access to water and participation in decision-making within communally managed rural water schemes remained substantially constrained despite existing policy and legislative provisions. Youth-led solar pumping initiatives further reduce physical burdens on women while strengthening household water security more effectively than conventional, top-down management models. However, scaling these gender-inclusive approaches requires explicit policy support to transition from isolated interventions to embedded institutional frameworks. Ultimately, sustainable water adaptation depends on embedding gender and intergenerational equity principles within governance structures and technological investments.

Policy implications: from recognition to institutional integration

The reviewed literature suggests that the central policy challenge is no longer simply whether local knowledge should be acknowledged, but how relevant local knowledge and community institutions can be connected to formal planning, implementation, monitoring, and maintenance without compromising technical standards, public health, or equitable participation. This requires movement from general statements about community participation toward defined institutional responsibilities. Table 11 translates reviewed evidence into water-governance actions.

First, participation should extend across the project cycle. Consultation during project initiation alone is insufficient if communities are subsequently excluded from implementation, maintenance, and monitoring. Evidence from Bududa indicates that stakeholder participation at all three stages (planning, implementation,

Table 11. Translating reviewed evidence into water-governance actions.

Evidence from the review	Governance implication	Practical policy action
Community participation in planning, implementation, and monitoring is associated with water-resource management in Bududa	Participation should continue throughout the project cycle	Require community and water-user committee involvement in planning, monitoring, reporting, and routine maintenance
Communities report failures and maintain water points	Local monitoring can complement district technical oversight	Establish clear reporting pathways between water-user committees and district water offices
Women contribute substantially to operation and maintenance but may have limited decision-making authority	Labor participation does not automatically create governance power	Include women meaningfully in budgeting, monitoring, planning, leadership, and infrastructure decisions
Mt Elgon stakeholders possess locally differentiated knowledge of water availability	Local observation can improve contextual understanding	Incorporate participatory environmental knowledge into planning alongside technical assessment
Improved water sources in Kibuku still showed water-quality problems	Infrastructure provision alone does not guarantee safe water	Combine infrastructure investment with routine water-quality monitoring, treatment, sanitary management, and community education
Cultural institutions can influence water-management legitimacy	Formal institutions should evaluate relevant customary structures	Develop context-specific co-management arrangements where cultural institutions support equitable and sustainable management

Source: Synthesis derived from the reviewed literature by the authors (Aggrey et al., 2024; Kimbowa et al., 2024; Mandu & Karyeija, 2024; Naiga et al., 2024; Namara et al., 2024; Walekhwa et al., 2022).

and monitoring) is associated with stronger water-resource management (Mandu & Karyeija, 2024). District-level water programmes should therefore specify mechanisms through which communities and water-user committees participate before and after infrastructure construction.

Second, community management requires continuing technical and institutional support. Devolution of maintenance responsibility without training, financial arrangements, replacement parts, or accessible technical assistance risks transferring responsibility without transferring adequate capacity. Research on collective water management in Uganda demonstrates both the importance of community action and the institutional constraints affecting its success (Naiga et al., 2017). Water-user committees should therefore be connected to district maintenance and reporting structures rather than expected to manage complex infrastructure independently.

Third, gender inclusion should be treated as a governance issue rather than simply a participation target. Women's substantial contribution to water management does not guarantee influence over decisions. Evidence that women continue to experience restricted decision-making in community-managed schemes indicates the need for institutional arrangements that give women meaningful authority in planning, budgeting, maintenance, monitoring, and dispute-resolution processes (Naiga et al., 2024).

Fourth, local environmental knowledge should complement rather than replace scientific monitoring. The Mt Elgon evidence demonstrates the value of stakeholder perceptions for interpreting environmental change, while the Kibuku evidence demonstrates the continued necessity of direct water-quality assessment even at improved water sources (Kimbowa et al., 2024; Walekhwa et al., 2022). A climate-resilient governance system should therefore connect community observation with hydrological measurement, sanitary inspection, water-quality testing, and technical infrastructure assessment.

Finally, cultural institutions should be considered where they contribute to legitimate and equitable management, but incorporation should be context-specific. Evidence from Karamoja shows that excluding culturally important institutions can create gaps between formal water-management models and locally embedded governance arrangements (Namara et al., 2024). Formal recognition should nevertheless depend on compatibility with equitable access, public-health standards, and accountable governance.

Despite considerable opportunities, the integration of TEK into climate-resilient water management in Uganda faces significant barriers. Although communities are frequently consulted, they remain excluded from formal decision-making processes (Tweheyo et al., 2024). Institutional frameworks systematically undervalue women's custodial knowledge (UN Women, 2022). Funding mechanisms for community-led innovations are either severely limited or absent entirely (Amani et al., 2023). Intergenerational transmission of TEK has gradually diminished owing to inadequate documentation practices (Haumba & Kaddu, 2017; Otim, 2024). These structural constraints substantially limit TEK's capacity as a tool for enhancing resilience. Addressing these shortcomings requires co-production of knowledge that is a collaborative framework in which communities, policymakers, and scientists operate as equal partners. Uganda's water adaptation policies can benefit from established best practices documented in regional and international contexts, as illustrated in Table 12 (Food & Agriculture Organization (FAO), 2018; UN Women, 2022; United Nations

Table 12. Best practices for co-production of water knowledge from regional and global examples.

Case study (region)	Co-Production practice	Lesson for Uganda
Kenya's ASAL counties	Joint community–scientist mapping of seasonal water sources	Integrating local mapping into planning improves accuracy
Ethiopia highlands	Combining traditional terracing with modern soil-water models	Hybrid practices strengthen resilience and adoption
India (Rajasthan)	Women-led water user associations	Gender-inclusive governance ensures sustainability
Bolivia (Andes)	Recognition of sacred water sites in law	Cultural legitimacy enhances community trust in policy

Source: Data synthesized from Kimbowa et al. (2024), Zvobgo et al. (2022), and Namara et al. (2024).

Development Programme (UNDP), 2022). Through co-production, the integration of local knowledge with scientific expertise strengthens policy legitimacy, broadens stakeholder inclusion, and promotes long-term sustainability (Table 12).

The evidence reviewed in this study indicates that climate-resilient water management in Eastern Uganda is not principally a choice between traditional knowledge and modern technology. Rather, resilience depends on how knowledge, infrastructure, community institutions, gender relations, maintenance systems, and government responsibilities are connected. Local knowledge can contribute contextual understanding of environmental change and community priorities; engineered infrastructure can expand and stabilize water services; water-quality monitoring can safeguard health; and community and government institutions can jointly sustain operation, maintenance, and accountability.

The strongest policy implication of the review is therefore the need to institutionalize supported co-management rather than relying exclusively on either top-down infrastructure provision or unsupported community self-management. This entails participatory planning, technically informed infrastructure development, clearly assigned maintenance responsibilities, meaningful participation by women, integration of appropriate local knowledge, and continuing links between water-user committees and district technical institutions. Such arrangements are more consistent with the evidence reviewed here than claims that traditional, modern, or hybrid systems are universally superior. The priority for future policy and research should consequently be to identify the institutional and environmental conditions under which these combinations produce reliable, equitable, and sustainable water-management outcomes.

Co-production of knowledge for climate-resilient water management

Co-production provides an institutional pathway for linking these different knowledge systems. Bremer and Meisch (2017) emphasize that co-production has multiple meanings within climate-change research and should be used transparently rather than as a generic synonym for participation. In the context of this review, co-production refers to an interactive process in which community knowledge holders, technical specialists, government institutions, and other stakeholders contribute to defining problems, interpreting evidence, developing interventions, and evaluating outcomes.

Applied to Eastern Uganda, co-production can operate at several stages of the water-management cycle. During planning, community observations of seasonal water availability, flood exposure, changing springs or streams, and patterns of access can complement hydrological and engineering information. During implementation, water-user committees and community members can contribute locally relevant knowledge, labor, institutional rules, and feedback concerning accessibility. During operation and maintenance, communities can identify malfunctioning water points, undertake appropriate routine maintenance, and communicate more complex failures to district technical personnel. During monitoring, locally observed changes in water availability and access can be considered alongside water-quality measurements, infrastructure records, and hydroclimatic information.

Borehole and water-point planning as an example of co-production. Water-point siting illustrates how this principle can be operationalized. Local residents can provide information about seasonal accessibility, historical water availability, land-use patterns, flood or landslide experience, and socially important locations. Technical specialists can then evaluate these observations alongside hydrogeological surveys, water-quality requirements, engineering feasibility, and statutory standards. Under this arrangement, local knowledge contributes contextual evidence while professional hydrogeological assessment remains essential for determining whether a proposed borehole or other water point is technically appropriate.

This approach is supported particularly well by the Bududa evidence. Mandu and Karyeija (2024) found that participation in planning, implementation, and monitoring was positively associated with water-resource management, while their qualitative findings documented community reporting of malfunctioning water points, routine cleaning, and interaction between water-user committees and authorities. The Mt Elgon study by Kimbowa et al. (2024) similarly demonstrates that different stakeholder groups possess relevant but not necessarily identical understandings of changes in water availability. Taken together, these studies support governance arrangements in which different forms of knowledge are compared and combined rather than assuming that one knowledge system can independently address all dimensions of climate-related water insecurity.

Research gaps and future directions

While local adaptation case studies have been documented (Food & Agriculture Organization (FAO), 2018), significant research gaps persist concerning the rigorous evaluation, scalability, and formal integration of TEK. Notably, few studies examine the long-term effectiveness or scalability of TEK approaches. Kenya's Water Act, which substantially recognizes customary water use, and Uganda's Catchment Management Planning Guidelines, which emphasize community stewardship despite uneven implementation, represent important policy precedents. Though adoption levels vary across the region, frameworks such as the SADC water policy increasingly promote the incorporation of local knowledge in basin planning. Beyond East Africa, community-based water management initiatives in South Asia and Southern Africa demonstrate the potential benefits of combining local administration with formal legal authority. Developing culturally appropriate adaptation pathways in Eastern Uganda will require addressing these evidence gaps through pilot projects, comparative assessments, and stakeholder-inclusive policy development.

The insufficient documentation of TEK represents one of the field's most critical gaps. Given that much of this knowledge is transmitted orally within women, elder, and traditional institutional networks (see Section 7), it remains vulnerable to erosion from modernization, migration, and shifts across generations. A comprehensive compilation of documentation-related deficiencies appears in Table 13 (Bwambale et al., 2018; Egeru et al., 2015; United Nations Development Programme (UNDP), 2022). Table 13 further underscores the importance of participatory archiving approaches, illustrating how inadequate recordkeeping undermines both formal legal recognition and scholarly integration of TEK.

A significant research gap exists in evaluating local adaptation techniques such as sand dams and rainwater harvesting systems where empirical evidence regarding their long-term sustainability and economic viability remains limited. To advance knowledge co-production and foster innovation, future research directions will emphasize Participatory Action Research (PAR), an approach that empowers communities to collaboratively design research initiatives alongside scientists and policymakers. As illustrated in Table 14, the field must

Table 13. Gaps in documentation and preservation of traditional ecological knowledge.

Gap area	Status	Implication for resilience
Oral transmission	Reliance on elders and custodians	High risk of knowledge loss
Lack of written archives	Few formal records in academic or policy systems	Limited incorporation into planning
Weak intergenerational transfer	Youth less engaged in TEK practices	Break in continuity of adaptive strategies
Inadequate policy recognition	TEK not systematically integrated	Missed opportunity for mainstreaming adaptation

Source: Compiled from Bwambale et al. (2018), Egeru et al. (2015), United Nations Development Programme (UNDP) (2022), and gaps identified in Haumba and Kaddu (2017) and National Environment Management Authority (NEMA) (2025).

Table 14. Future research directions for climate resilient water management.

Research area	Proposed approach	Expected outcome for adaptation
Documentation of TEK	Oral history projects, community archives	Preservation of knowledge across generations
Effectiveness evaluation	Comparative studies on cost-benefit of TEK vs modern approaches	Evidence-based scaling of adaptation strategies
Gender and water governance	PAR focusing on women and youth roles	Inclusive adaptation frameworks
TEK policy integration	Policy labs combining local and national actors	Institutionalized co-management systems
Innovation pathways	Testing hybrid TEK modern water technologies	Scalable and sustainable innovations

Source: Proposed future research directions based on gaps in Bremer and Meisch (2017), Food and Agriculture Organization (FAO) (2018), Zvobgo et al. (2022), and participatory approaches in Namara et al. (2024) and Saber et al. (2025).

transition from descriptive studies toward comprehensive assessment, inclusive engagement, and innovation-oriented pathways.

The data presented in [Tables 13](#) and [14](#) identify three critical research priorities:

- i. Systematic documentation of TEK to ensure its preservation and prevent further erosion.
- ii. Comprehensive evaluation of adaptation effectiveness using quantifiable indicators such as water security, gender equity, and cost efficiency.
- iii. Collaborative knowledge production among communities, academic institutions, and policymakers through participatory action research.

Beyond contributing to scholarly advancement, addressing these gaps can facilitate the development of policy frameworks that are both socially and scientifically rigorous.

Conclusion

Enhancing climate-resilient water management in Eastern Uganda requires greater integration of traditional ecological knowledge and locally developed adaptation strategies. Traditional knowledge systems encompass diverse ecological and cultural practices including rainwater harvesting, well maintenance, water purification methods, collective action initiatives, and community governance frameworks that have historically enabled communities to navigate challenges such as prolonged droughts and rainfall variability. These approaches have been reported to support both household and communal resilience.

The assessment further underscores the importance of gender-differentiated roles, whereby elders maintain governance structures and cultural continuity, women function as custodians of water-related knowledge, and youth provide labor and creative contributions ([Section 7](#)). Planning processes demonstrate greater equity and effectiveness when such gendered dimensions are explicitly recognized and integrated into decision-making frameworks.

While it can conflict with hierarchical governance frameworks that overlook cultural norms, integrating TEK with modern water management practices generates valuable synergies such as hybrid rainwater harvesting systems and community-based borehole maintenance programs. Policy analysis identifies promising avenues for incorporating TEK into water governance structures while simultaneously revealing significant gaps in funding, stakeholder engagement, gender representation, and institutional documentation. Addressing these challenges requires participatory research methodologies, collaborative knowledge production, and active support for community-led innovation initiatives.

This review highlights significant research gaps in three areas: assessing adaptation effectiveness, integrating local knowledge into policy frameworks, and systematically documenting TEK. The findings emphasize an urgent imperative to document and recognize traditional knowledge systems as essential components of climate-resilient water management. Given the escalating climate threats facing the region, policymakers and stakeholders in Eastern Uganda must adopt inclusive, participatory approaches to achieve sustainable water management outcomes.

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ORCID

Esther Ugo Alum  <https://orcid.org/0000-0003-4105-8615>

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Consent to participate

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Consent for publication

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